MULTIPACTING IN HOM COUPLER OF LCLS-II 1.3 GHz SC CAVITY*

G. Romanov#, A. Lunin and T. Khabiboulline, Fermilab, Batavia, Illinois, USA

Abstract

During high power tests of the 1.3 GHz LCLS-II cavity on the test stand at Fermilab an anomalous rise of temperature of the pickup antenna in the higher order mode (HOM) coupler was detected in accelerating gradient range of 5-10 MV/m. It was suggested that the multipacting in the HOM coupler may be a cause of this temperature rise. In this work the suggestion was studied, and the conditions and the location, where multipacting can develop, were found.

INTRODUCTION

During high power tests of the 1.3 GHz cavity for Linac Coherent Light Source (LCLS-II, [1]) on the test stand at Fermilab an anomaly rise of temperature of the pickup antenna in the higher order mode (HOM) coupler was detected in accelerating gradient range of 5-10 MV/m, while nominal gradient is 16 MV/m. It was suggested that multipacting (MP) in the HOM coupler may be a cause of this temperature rise due to energy deposition of MP electrons at bombardment sites. The multipactor (MP) in the HOM couplers of TESLA-type cavities is a known phenomenon that was studied already in a number of works (see [2, 3, 4] for example). Apparently the MP is not very powerful, since there is no noticeable temperature rise of other parts of HOM coupler besides the antenna. On the other hand the pickup antenna has much less effective cooling compare to the HOM coupler in general, so even a small energy deposition can heat it and be a reason of thermal runaway. Therefore we were searching MP in the given interval of accelerating gradients that would deposit energy directly on the antenna body.

The search of the MP was performed with the use of CST Studio Suite. The electromagnetic fields inside the coupler were calculated by eigenmode solver. Then the properly scaled fields were imported into PIC solver and the particle tracking was performed using our usual approach [5]. The eigenmode HOM coupler model and the fields imported into PIC solver model are shown in Fig.1.

MP IN THE NOMINAL HOM COUPLER GEOMETRY

At first the search of MP was performed in the HOM coupler of nominal geometry. In this geometry a gap of the HOM feedthrough ("coupling" gap) is 0.5 mm corresponding to the drawings. Other important gap ("filter" gap) is used to tune filtering properties of the HOM coupler. This gap is about 2 mm (the end wall is not flat, so the distance is approximate). Both gaps are shown in Fig.2.

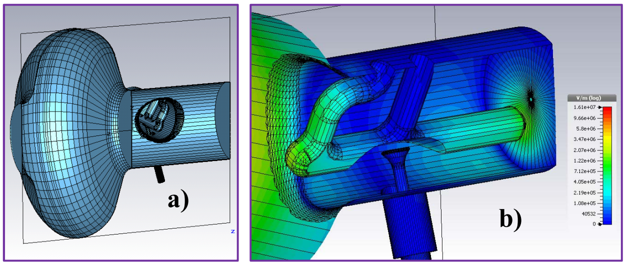

Figure 1: a) Eigenmode model of HOM coupler; b) Electric field imported into PIC model.

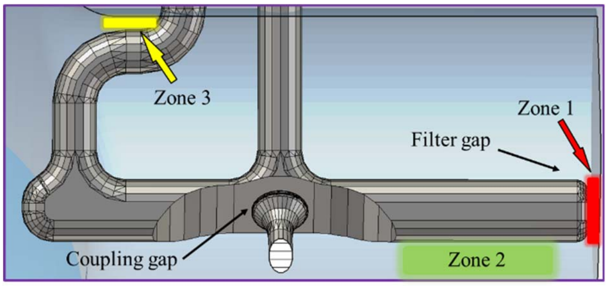

Figure 2: The known zones of multipacting.

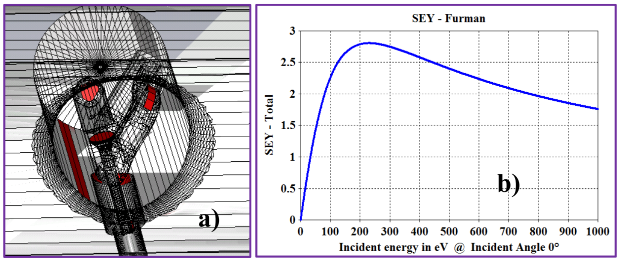

Figure 3: a) Locations of the particle sources; b) Total SEY of the wet treated niobium from CST material library.

The sources of primary electron were placed in all possible locations of MP as shown in Fig.3a. Secondary emission yield curve (SEY, also shown in Fig.3b)) was taken from the CST material library. It corresponds to wet treated niobium. Obviously, a real surface is much better cleaned, but the wet treatment data was chosen deliberately because high SEY helps to find all dynamically possible MP cases.

In general, the simulations just confirmed what was found in the previous studies [2, 3, 4]: namely, there are three zones, where multipacting develops at different accelerating gradients (see Fig.2). The result in the form of <SEY> vs accelerating gradient is shown in Fig.4, where <SEY> is a ratio of total emission current to total collision current averaged over last 5 RF periods of simulation. Value of <SEY> greater than 1 indicates particle multiplication. Only one new addition to the known results is a non-resonant MP [5, 6, 7], which develops in zone 2 at E_{acc} = 5-10 MV/m. Usually this kind of multipacting is missed if the simulations are performed with single-trajectory tracking codes.

---

*Operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

#gromanov@fnal.gov

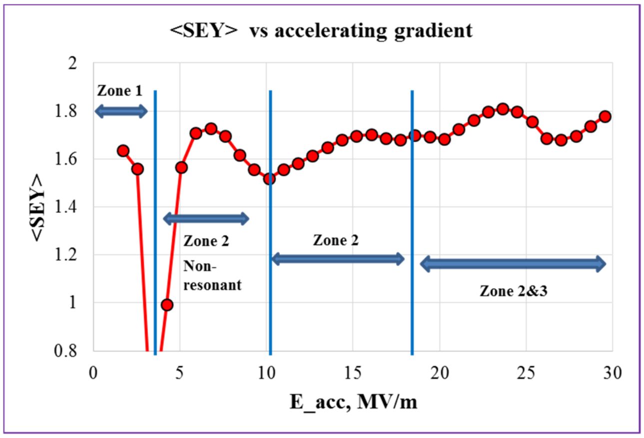

Figure 4: Effective <SEY> in the HOM coupler of nominal dimensions.

All these MP cases do not generate sufficient power deposition on the pickup antenna (less than 0.1% of total collision power falls on the antenna) that could explain thermal runaway during high power tests. The simulations with positive potential on the antenna showed increasing of particle deposition by 1-2 orders, but there is no reason to assume that some self-charging of the antenna due to particle bombardment may happen.

Therefore, normally the antenna heating due to multipacting in the mentioned areas should not occur.

MP IN THE COUPLING GAP

The most natural MP process that could explain the antenna heating would be multipacting directly in the coupling gap. But for nominal gap size of 0.5 mm there is no conditions for multipacting, since parameter f·d is less than theoretical threshold of 80-90 MHz·cm, where f is operating frequency and d is size of the gap. This threshold of 80-90 MHz·cm is confirmed by many experiments, and MP of any type cannot exist below it [8].

On the other hand, parameter f·d is very sensitive in our case due to high operating frequency, and it exceeds the threshold already at d=0.615 mm. It is possible that such small deviation can happen due to inaccurate assembly, excessive etching or misalignment. To check this the coupling gap was set to 0.9 mm (the size was chosen to ensure an excitation of MP). The fields in the HOM coupler have been re-simulated with this gap size. The electric field distribution in the gap is extremely non-uniform and even changes its sign (see Fig.5a)). Nevertheless, the resonance MP develops in the gap as expected as shown in Fig.6.

The simulations of multipacting as a function of accelerating gradient indicated a threshold of the MP barrier for d =0.9 mm as low as E_min = 14.35 MV/m. Since E ~ d, then for d = 0.615 mm MP barrier would start at E_min = 9.8 MV/m. It is slightly higher than the high power tests demonstrated. A factor that can decrease MP threshold is a quality of HOM coupler tuning, i.e size of the filter gap. Properly tuned HOM coupler has minimal electric field in the coupling gap, and the field has zero line across the antenna tip (see Fig.5a). Deviation of the filter gap size from optimal value moves this zero line away and increases average level of electric field (see Fig.5b)). As a result E_min can be significantly lowered as low as the experimental threshold of 5 MV/m (for the filter gap decreased by 0.5 mm).

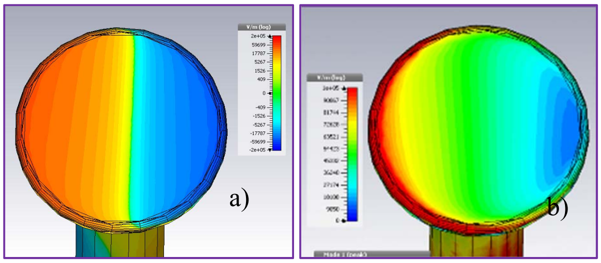

Figure 5: Distribution of electric field component normal to surface on the antenna tip for properly tuned coupler a) and detuned coupler b).

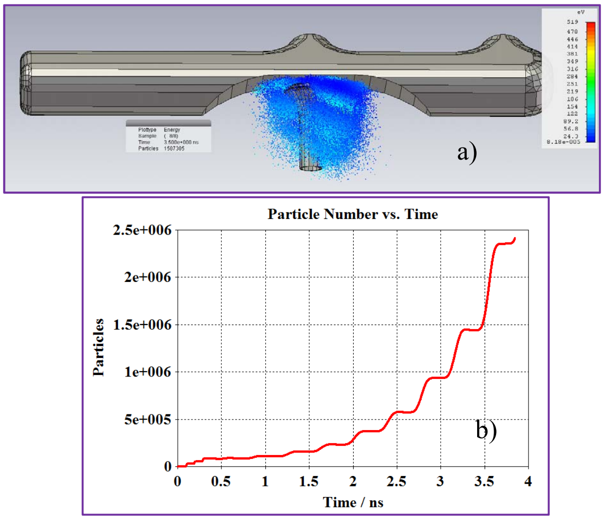

Figure 6: a) Multipacting in the coupling gap of 0.9 mm. b) Particle number growth in the gap at accelerating gradient of 12.7 MV/m.

ON POSSIBILITY OF DARK CURRENT GENERATION BY MP IN HOM COUPLER

It was suggested that the multipacting in HOM coupler of the 1.3 GHz LCLS cavity can be a source of dark current in the cavities of this part of the accelerator. The suggestion was based on the fact that the secondary electrons generated by the MP discharge come out from the HOM coupler into the beam pipe between cavities and there can be captured in acceleration.

The check this speculation the study was performed with the use of CST Studio Suite as before. The electromagnetic fields inside the coupler were calculated by eigenmode solver. But this time the beam pipe in the model was longer and mesh density in it was the same as for HOM coupler parts to enhance accuracy of tracking (see Fig.7).

Then the electromagnetic field maps were imported in PIC solver, and the multipacting simulations were performed at accelerating gradient of 15 MV/m, which is the highest MP barrier in Zone 2 close to the operating gradient. The model for MP simulation is shown in Fig.8. In this model the cavity cell was replaced with extension of beam pipe to reduce number of meshcells.

At the ends of the PIC model two metal plates were installed to collect the particles, measure their parameters and total incident current (sort of Faraday cups). The simulations were done with space charge effect ON, so, number of particles does not grow exponentially, but comes to a saturation. Therefore an incident current is practically constant after certain time of MP development (see Fig.9). Actually slight increasing of total number of particles still continues longer due to the accumulation of very slow particles in the beam pipe, but it can be neglected.

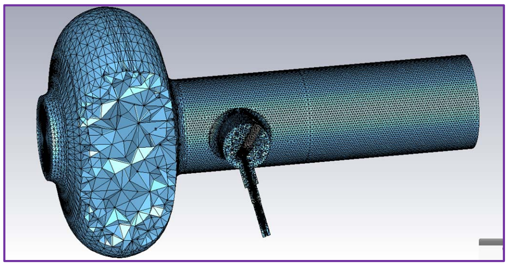

Figure 7: Eigenmode model of the HOM coupler.

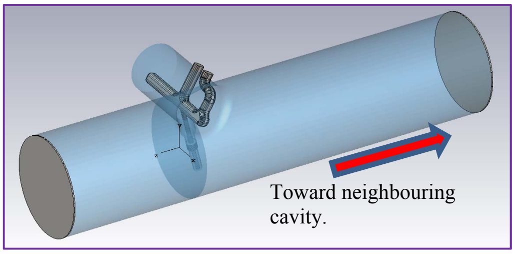

Figure 8: The model for PIC simulations.

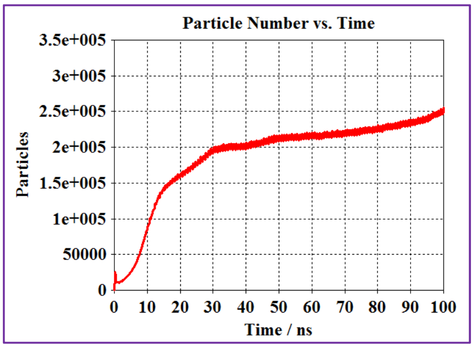

Figure 9: Number of particles in the beam pipe vs time.

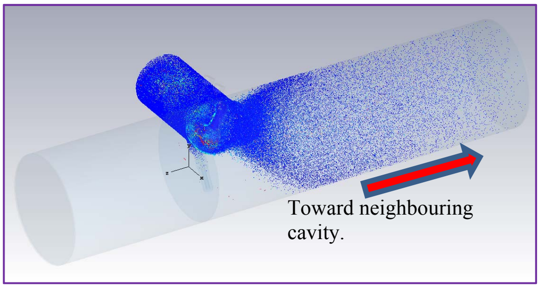

Figure 10: Propagation of the particles in the beam tube.

The developed stage of multipacting is shown in Fig. 10. It is a remarkable phenomenon that all electrons are moving toward a neighbouring cavity due to the Miller effect. The “Faraday cup” at the left end of the model does not indicate even a single electron. The total electron current that reach right end of the model is 2% of total re-emission current generated in the HOM coupler. Average energy of the electrons colliding with the right “Faraday cup” is 4 keV, some random electrons gain 25 keV.

CONCLUSION

This study showed that in properly assembled and properly tuned HOM coupler the known MP cases do not heat the pickup antenna. At the same time it was demonstrated that a combination of coupling and filter gaps deviations can create conditions for specific multipacting in the coupling gap. This MP can be responsible for the antenna heating. To avoid this situation the nominal parameters of the coupler should be very accurately fulfilled. Other remedy is increasing of the coupling gap up to 1.5 mm. A larger gap shifts electric field interval where MP resonance conditions exist up to the level that cannot be reached under normal operation, while degradation of the damping efficiency for the most dangerous HOM is quite moderate (≈ 10%).

The electrons generated by multipacting in the HOM coupler do not enter the first cell of a cavity to which HOM coupler belongs. The maximal energy of the electrons that tried and failed to penetrate field gradient barrier was up to 80 keV. We assume that the electrons that may reach a neighbouring cavity will be bounced back as well since they have much lower energy (< 20 keV). Therefore we conclude that multipacting that may occur in the HOM couplers of 1.3 GHz cavities cannot contribute to or initiate the dark current.

REFERENCES

[1] J. N. Galayda, “The Linac Coherent Light Source-II Project”, in *Proc. IPAC’14*, Dresden, Germany, 2014, paper TUOCA01, pp. 935-937.

[2] I. Gonin *et al.*, “Multipactor Simulations in Superconducting cavities”, in *Proc. PAC’07*, Albuquerque, New Mexico, USA, 2007, paper WEPMN093, pp. 2248-2250.

[3] Y. M. Li *et al.*, “Comparative Simulation Studies of Multipacting in Higher-Order-Mode Couplers of Superconducting RF Cavities”, *Phys. Rev. ST Accel. Beams*, vol. 17, p. 022002, 2014.

[4] D. Kostin *et al.*, “Multipacting in HOM Couplers at the 1.3 GHz 9-Cell Tesla Type SRF Cavity”, in *Proc. SRF’2011*, Chicago, IL, USA, 2011, paper THPO003, pp.691-694.

[5] G. Romanov *et al.*, “Simulation of Multipacting in SC Low Beta Cavities at FNAL”, in *Proc. IPAC’15*, Richmond, VA, USA, 2015, paper MOPMA018, pp. 579-581

[6] L. V. Grishin, A. A. Dorofeyuk., I. A. Kossyi, G. S. Luk“yanchikov and M. M. Savchenko, “A Study of Secondary-Emission Microwave Discharges with Large Electron Transit Angles”, *Lebedev Physics Institute Series*, vol 92, New York: Consultants Bureau, pp 63–101, 1977.

[7] L. V. Grishin and G. S. Luk’yanchikov, “Multipactor discharge with an electron velocity distribution”, *Sov. Phys. Tech. Phys.*, vol. 21, pp. 307–311, 1976.

[8] И.Н. Сливков, “*Процессы при высоком напряжении в вакууме*”, Москва, Энерго-атомиздат, 1986, стр. 226-234.